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SLURRY MEASUREMENT TECHNIQUES - B

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1 INTRODUCTION

The previous paper has discussed measurement of fine particle homogeneous slurries in which there are no settling effects. This paper is concerned with slurries which have a settling tendancy i.e. they require a certain degree of agitation or movement to maintain the coarsest particles in suspension. These are termed heterogeneous slurries. The simplest heterogeneous slurries consist of near mono sized discrete grannular particles in water e.g., beach sand in water. More complicated slurries are those involving both fine and coarse particles. In this case the fine particles cause an increase in the viscosity above that of water. The coarser particles can be envisaged as being suspended in a high density viscous carrier fluid. In many cases this carrier fluid will possess a yield stress. This may be sufficient to suspend the coarsest particles when the slurry is static. However once the slurry is sheared this supporing mechanism is lost and dynamic effects must prevent particles settling.

2 SLURRY CHARACTERIZATION

The major measurements required to characterize a slurry are:

Particle size
Solids SG
Viscosity
Concentration
Surface Chemistry aspects - pH, Coagulants, flocculants, thinners
Slurry abrasivity

Particle Size

A particle size distribution is required. For particle sizes above about 50 microns standard sieving methods can be used. Below this other methods must be used such as sedimentation techniques, cyclosizer, microscopy, and most recently the laser beam instrument. An important point to note however is that sub-sieve particles mainly influence slurry behaviour through their effect on the viscosity and so their actual size is relatively unimportant. This means a sieve analysis is generally all that is required.

Solids Density

The density of the dry solids needs to be determined by standard density bottle techniques. The likely variation in this density from sample to sample is important as is any variation with particle size. With coal particles the density varies strongly with ash content and this relationship should be determined. When pumping coal slurries some ash can be leached out with a consequent reduction in solids density. This effect can be conveniently studied in a wheelstand test rig (Thomas, 1986). A further complication with coal slurries is that the effect of inherant moisture on particle density needs to be addressed.

Viscosity

Particles less than 50 microns can strongly influence the viscosity. Viscosity measurement relies on shearing of the slurry. The most convenient instrument is the rotational viscometer with the cup and bob arrangement. To obtain high shear rates the gap width is usually small, of the order of a few millimetres. To avoid jamming, all particles greater than about one third of the gap width should be screened out. Typically this might mean screening at 0.5mm. Maximum shear rates are generally in the range 500 to 1000 sec^{-1} for "thin" slurries reducing to around 100 to 200 sec-1 for thicker slurries.

These relatively low shear rates are not a serious limitation for pipeline hydraluic prediction. The thicker slurries will be pumped under laminar flow conditions with the relevant shear rates at typical pumping velocities being relatively low. This means the viscometer data can be used directly to predict laminer flow pipe performance. The situation with thinner slurries is not so straight forward since they will often flow under turbulent conditions at normal pumping velocities. There are a number of proposed theories for predicting pressure gradient of non-Newtanian slurry flow. Some of these e.g. Hanks & Dadia (1971) are based on the Bingham plastic model which requires data at high shear rates to accurately determine the parameters. A more recent analysis (Wilson and Thomas, 1985) also requires high shear rate data since it requires laminar flow data up to shear stress values equal to those present in turbulent flow. Obtaining this high shear rate data can be a problem with rotational viscometers. Tube viscometers can generally attain high shear rates so they can be used although they are less convenient.

The heterogeneous effects associated with the settling tendancy of the plus 0.5mm size particles still have to be allowed for. For turbulent flow conditions the sliding bed theory of Wilson (1976) is most relevant. The question of what is the relevant viscosity to use when calculating the particle settling velocity immediately arises. Use of the Bingham plastic viscosity, which equals the effective viscosity at infinite shear rate, tends to overestimate the settling velocity and the correct viscosity value appears to be somewhere between this viscosity and the effective viscosity at the wall shear stress in question.

The effect of coarse particles under laminar pipe flow conditions is a poorly understood area. Work of Kenchington (1976), Thomas (1979) and Duckworth et at (1983) is relevant.

Concentration

For slurry characterization the concentration is most easily determined by oven drying a sample. Viscometer tests ar three or four different concentrations will generally provide sufficient data to allow interpolation of properties to intermediate concentrations. To aid interpolation it is convenient to fit rheological models to the date such as the Bingham plastic, the power law and the yield power law.

Surface Chemistry Aspects

As the size of particles is reduced body forces between particles became more predominate as do surface forces. Addition of coagulants such as Alum, thinners such as polyphosphates and pH changes, will all alter the degree of attraction between particles. This alters the viscosity. In terms of the Bingham plastic model these chemical changes tend to alter the yield stress with the plastic viscosity remaining constant. Polymer flocculants are commonly used in mineral process plant thickeners. These act by the polymer molecules forming bridges between the particles. Flocculation increases the yield stress but usually not by the same degree as it increases the settling rate. These flocculated slurries are not very stable with the flocs being easily broken by shearing.

Slurry Abrasivity

The abrasivity of the slurry and the particle size affect the likely pipe and pump wear rates. A popular abrasivity criteria is the Miller number (Miller 1974). This test was developed to predict wear rates resulting from rubbing type abrasion occurring in reciprocating pumps. It is sometimes used in predicting pipe wear rates, but it is not ideal in this regard. The wheelstand test rig is more suited for this purpose (Thomas, 1986).

3 ON-LINE MEASUREMENT

On-line measurement techniques are governed by the overiding necessity for the instrument to be non-invasive. Slurries, by nature, are erosive to various degrees and so, many instruments which are used in water and gas applications are unsuitable for slurry service. Further requirements are the need to avoid clogging and to allow for effects of any slurry segregation.

The principal quantities of interest are:

Pressure
Flow rate
Density
Viscosity

Pressure

For monitoring of slurry pressure standard pressure gauges and transmitters are used in conjunction with isolating diaphragms, suitably mounted to avoid settling blockage problems.

Flow Rate

The magnetic flow meter is the most commonly used flow measurement instrument. The main limitation concerns slurries containing magnetic minerals. Even in nominally non-magnetic slurries, trace amounts of magnetic material can foul the electrodes. Self cleaning electrodes subjected to periodic ultrasonic vibration are available to overcome this. Magnetic flow meters are insensitive to velocity profile changes providing the profiles are axisymmetric. Thus flow changes from laminar to turbulent flow have no effect on the accuracy. Non-axisymmetric velocity profiles do affect the accuracy and so with hetrogeneous slurries the flow meter should be placed in a vertical section of pipe.

Ultrasonic doppler flow meters which strap onto the outside of the pipe are also suitable for slurry use. They have the advantage of portability, but are sensitive to velocity profile changes and particle concentration and distribution. Because of this they should be field calibrated.

For small flow rates the Coriolis effect mass flow meter is a useful instrument although it is very susceptible to pipe wear. For homogeneous slurries the venturi tube can be used to measure flow rae.

Density

The nuclear density gauge is a reliable non-invasive strap-on type instrument widely used in industry for on-line density measurement. Knowing the density of the liquid the solids concentration can also be monitored. This instrument measures the in-situ density. With heterogeneous slurries the in-situ concentration may be significantly different from the delivered concentration. For this reason the gauge should be located on a vertical section of pipe with velocities sufficiently high to ensure minimum holdup of solids.

Other less satisfactory methods of density measurement include static pressure measurement and weighing a length of horizontal pipe. The Coriolis effect mass flow meter can also measure slurry density.

Viscosity

On-line measurement of viscosity, although in principle simple, is in practice quite difficult. Reliability and avoidance of bockages are of prime consideration. The two basic approaches use either the tube viscometer or the rotational viscometer principle. Both types are currently on the market. The tube viscometer is inherantly the simplest and with proper design to avoid blockages during shutdown etc is reliable. With rotational viscometers considerable complication is needed to sample the required quantity and avoid blockage and settlement problems.

Both types essentially measure the effective viscosity at a single shear rate. For a non-Newtanian fluid this does not fully characterize the flow curve, but this is not a serious limitation for on-line control purposes.

Direct shear stress measurement instruments are available, but these measure the product of velocity and viscosity and so require velocity measurement to obtain the viscosity. They are also susceptible to wear and blockage problems.

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